RICHTMANN PUBLISHING

Development of a 3D Printing Strategy to Improve the Level of Abstraction in the Generation of Orthogonal Projections

Carlos Alexis Alvarado-Silva[1*]

Silvia Yvone Gastiaburú-Morales[2]

Karina Liliana Gaytan-Reyna[1]

Sassy Emperatriz Gaytan-Reyna[3]

Fernando de Azevedo Silva[4]

[1]Research Department,
Universidad César Vallejo,
Perú
[2]Mechanical-Electrical Engineering Department,
Universidad Señor de Sipán,
Perú
[3]Postgraduate Department,
Universidad Nacional de Trujillo,
Perú
[4]Mechanical Engineering Department,
Universidade Estadual Paulista "Júlio de Mesquita Filho",
Brazil

Abstract

Using the 3D printing method as an engineering teaching tool has been intensifying and implemented throughout all the courses of the engineering career and even in research departments, this means that it not only fulfills the functions for those that were originally designed (manufacturing of parts) but as a support for the acquisition of other important skills in future engineers. The research has a quantitative approach, experimental design with a control and experimental group of 35 and 37 students respectively. For its execution, a pre-test and post-test have been used as instruments, which were applied to students of a Technical Drawing subject of the career of Mechanical-Electrical Engineering. The findings reveal that the proposed teaching strategy using 3D printed elements significantly improves the level of abstraction for the generation of orthogonal projections. After the experiment, the control group showed an improvement in average grades of 20.3%, this indicates that the application of traditional teaching improves the level of abstraction. In the case of the experimental group, a higher average of the grades was obtained with a 30.8% improvement, which means that the students felt more comfortable with the proposed teaching strategy. On the other hand, the proposal was well received by the students who participated in the session, as they stated through the satisfaction survey that they were 90% between satisfied and very satisfied.

Keywords: 3D Print, Orthogonal Projections, Technical Drawing, Level of Abstraction

1. Introduction

A short time ago, graphic representation subjects in engineering schools were essentially based on descriptive geometry, as well as on disciplines related to manufacturing. (Tramonti et al., 2023). This subject, through graphic techniques, is based on transferring information from a 3-dimensional body to a 2-dimensional surface. (plane) (Renner & Griesbeck, 2020). The technical drawing and descriptive geometry courses required a deep memory of the representations and, above all, a spatial ability, because a solid, however complex it may be, had to be sketched with pencil and on paper through projections (Alhonkoski et al., 2021).

However, the development of technology has generated a constant change in thinking and teaching, and the graphic subject is also involved in this topic. Carrying out the designs using 3D virtual platforms has transformed the production process and also helped to optimize the drawing phase in all its stages and processes (Mihasan, 2021). Technical drawing with the assistance of 3D CAD software has made it possible to exclude pencil and paper procedures, optimizing time for drawing, even improving the spatial ability (De Souza Almeida et al., 2020).

Technologies have provided instruments and equipment available for didactic use (Carlos Vives Garnique et al., 2021). The hypermedia resources developed by the specialists allow students to access links, videos, animations and media that can support the teaching process pedagogically designed for this purpose. (Alexis Alvarado Silva et al., 2021).

The advances in formative teaching in the subject of technical drawing have been changed by innovative notions in graphic elements through the use of appropriate approaches for training, as well as by the variation in the perspectives of the community and the change in the requirement of cutting-edge knowledge in the workplace of the profession, coupled with the progress of technology and science (Turner et al., 2017). Currently, existing computers are increasingly accessible, powerful and with improved software, which allow unthinkable levels of visualization (Letnikova & Xu, 2017).

Although, it is known that most of the teachers of engineering drawing subjects are not specialists in teaching; this is restrictive since the teacher would limit its sessions to having a systematic and sequential programming of the development of the topics in the classroom, this implies that he does not select or apply innovative methods, innovative technologies, or adequate skills, without promoting the relevant platform for developing learning processes (Koido et al., 2013).

On the other hand, the engineer requires to participate with a graphic terminology of which he must lead and have the ability mainly to handle spatial intelligence (Lino Alves & Duarte, 2022). The teachers of the technical drawing subjects on some occasions detect that there are students who have difficulty working on certain drawings and at the same time linking them with the projections they represent, although in other subjects they develop perfectly, it is essential that the teacher identify this problem in the students (Triantafyllou, 2022).

In the discipline of technical drawing, it is verified that students have difficulty managing spatial ability, this influences their academic performance and academic training as professional graduates, just as sometimes the lack of encouragement leads the student to decide to drop out and change career where you don't have to handle this skill (Villa et al., 2018).

In the context of research in the field of engineering technical drawing, the following manifestations have been observed (Alvarado-Silva et al., 2023):

- Difficulty in adapting didactic situations in different learning contexts.
- Insufficiency in the management of the information provided.
- Difficulties to express ideas that envision the method of solving the problem of graphic representation.
- Deficiencies in the interpretation of the geometric results from its application.
- Insufficiency in the development of spatial intelligence does not favor the solution of practical difficulties of technical drawing.
- Limited comprehensive academic retention that contributes to correct performance.

The possible causes that generate this problem are given in:

- Deficiencies in the formative intention limit the spatial ability in solving graphic geometric problems in technical drawing.
- Practical restrictions in the teaching-learning process of engineering drawing in the solution of geometric descriptions
- Insufficient references corresponding to the theoretical and practical in the development of the teaching procedure-learning of the matter in the solution of geometric graphics in technical drawing.
- Insufficient didactic-methodological training of teachers in the development of the teaching procedure-learning of the subject of technical drawing.
- Insufficiencies in the didactic and methodological knowledge of the procedure for adjudication of course information, with emphasis on its apprehension and applicability that affect spatial ability in professional training.
- Insufficiencies in the epistemological and praxiological disposition in the interpretation of writing, problematizing the programming related to the training of spatial ability in the field of technical drawing in engineering.
- Limitations in this methodological procedure of teaching-learning with a rationality of drawing and geometry (Violante et al., 2020).

Thus, the main focus of the present investigation derives from the formative teaching strategies of technical drawing in the students, the present exploration project seeks to improve the spatial ability, introducing an innovative didactic methodology using a 3D Printer, which will be evidenced at through the generation of orthogonal projections, on the other side, it seeks to improve academic efficiency, in addition to linking academic training to the intellectual processing of students, in this way a necessary teaching tool would also be provided to teachers of the technical drawing course, that could be put into practice.

2. Methodology

The study is framed in the experimental approach, it corresponds to the quasi-experimental design with a control and experimental group, where each group will be applied a pre-test and post-test, the variable that will be manipulated (independent variable) will be the innovative didactic strategy to improve the level of abstraction to generate the orthogonal projections (independent variable). To measure the level of abstraction before and after applying the proposal, it will be measured through an objective test of 10 questions with multiple choice, which was validated by expert judgment.

The population was made up of students from the Mechanical-Electrical Engineering Career, the type of sampling used was non-probabilistic for convenience. Two groups of 35 and 37 students corresponding to the experimental and control group, respectively, were considered. For the experimental group, a session was applied using 3D printed geometric solids. The model of the printer used in this research is Bambu Lab X1 Series, for the control group a traditional session was used using markers, blackboard and slides.

3. Results

3.1 Pre-test Diagnosis

Before starting the session, an objective test was applied which purpose was to collect information on the student's prior knowledge. This test consisted of showing different images of the main views (mainly front, top and side) and the isometric view was indicated in the way the student had to choose which were the orthogonal projections that corresponded to the image, this method for evaluation was considered by a practical purpose since it was proposed to develop the didactic

strategy in a single session of approximately 3 hours, which corresponded to the class hours regularly assigned to the session. Figure 1 shows three examples of question that were applied in the objective test.

The results of the Pre-test are shown in Table 1, the control and experimental groups obtained an average grade between 5.11/10 and 5.14/10, and a standard deviation of 2.145 and 1.881 respectively, very approximate values that demonstrate that both groups are in the same level of knowledge and abstraction capacity for the generation of orthogonal projections before applying the didactic strategy.

Table 1: Descriptive statistical measures of the results of the objective test (pretest)

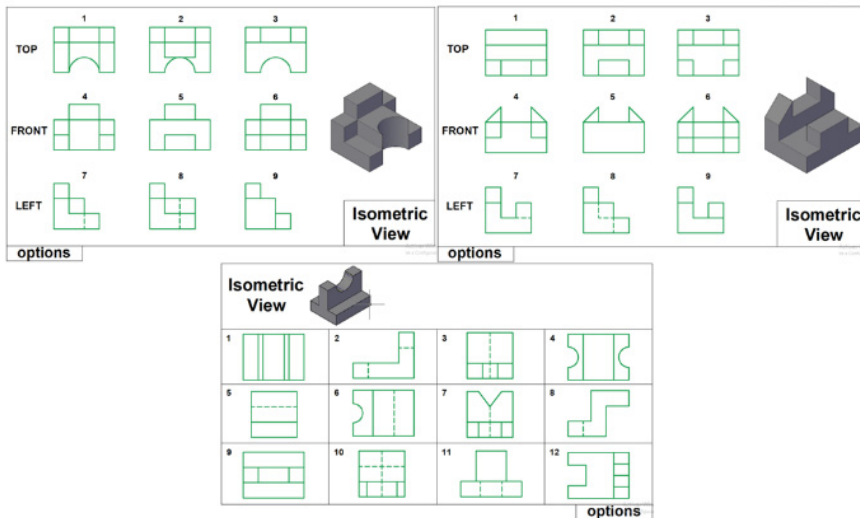| Group	n	Mean	Standard Deviation	Deviation Average error
Control	37	5.11	2.145	0.353
Experimental	35	5.14	1.881	0.318

Figure 1: Diagnostic assessment with multiple choice to assess the level of the students.

3.2 *Development of the Session.*

The teacher begins the session contextualizing the importance of obtaining three main views from a geometric solid. After having explained the main topic to the students for the generation of orthogonal views from an isometric view, different exercises are given to obtain main views: top, front view and left side view considering some standard.

During the abstraction process in which the student tries to represent the solids in the three cartesian axes, it is very common they have questions or doubts related to inclined planes, curved faces, conical or concave parts, holes of different shapes (Figure 2). All these geometric forms problems in three dimensions could make that the student misinterpret the axonometric representation of the solid.

In the teacher's work, many times an attempt is made to explain these problems to the student using gestures, expressions with the hands, or any material that is at hand such as a ruler, a pen, or some tools that often have shapes similar to those of the isometric view so that the student understands the geometry not being the indicated ones or without much success (Üçgül & Altıok,

2023), In some situations, for some students, this could work, but in some others, it is not possible for the student to reach the level of abstraction necessary to meet the competence outlined by the discipline of study. (Stavridi, 2017).

Thus, the research proposal uses 3D printing to manufacture the 3D elements, which present difficulties in obtaining the main projections from the isometric view in such a way that the student can help itself with the printed solid, being able to move and position it accordingly. So that it can be visible in its three axes, corroborating the proper way in which it should be presented the drawing in its projections (Trust & Maloy, 2017).
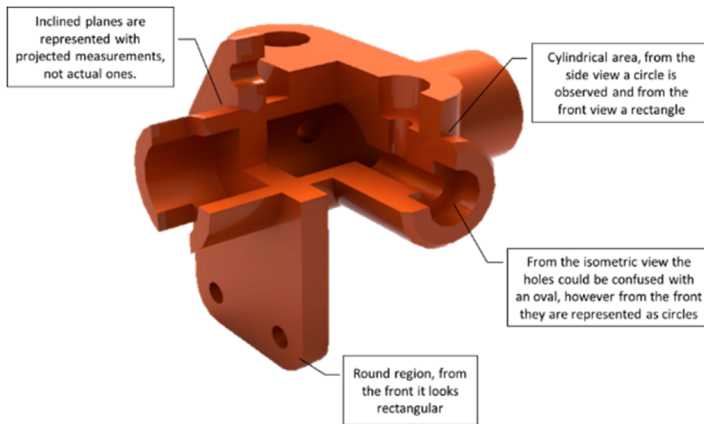

Figure 2: Common problems that students deal with during the abstraction process to generate the three main projections from the isometric view.

The printing procedure, represented in Figure 3, begins with the drawing of the solid (model) in three dimensions that could be supplied by the teacher using a CAD software, to be later loaded using the printer integrated software. For this project a *Bambu Lab* software was used, the selected model is inserted into the center of the printer bed. The next step considers the print settings: padding, resolution, orientation, temperature, speed, among others. Finally, depending on the chosen settings the element is manufactured by the printer using the fused deposition method (Mihasan, 2021).
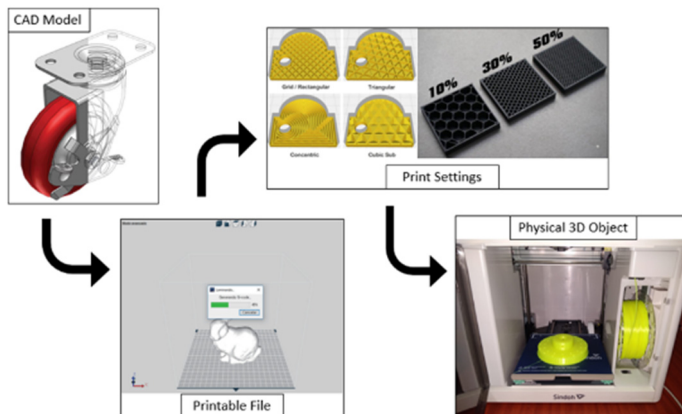

Figure 3: Printing process divided into its four main stages.

The student, once with the printed solid, can identify the areas in which he had doubts, in this way the error will be fed back without the need for the teacher to be able to gesticulate or orally explain the fault present in the drawing (Jafri et al., 2022). Thus, one of the greatest benefits of the proposed strategy consists in the direct interaction with the solid, the isometric view is a representation of a geometric solid in a plane considering that an angle of 60 grades that's why is not possible to rotate the graph, in that sense using the 3D printed element, the student with the solid could rotate the element from its three main axes from the top, the left side and the front as seen in Figure 4.A

Another form of interaction that turns out to be a significant experience for the student consists of taking measurements of the printed object using a vernier, also gaining an additional skill related to metrology (Renner & Griesbeck, 2020), thus, the student is not only limited to obtaining isometric views but could also obtain information such as length and angles for a real solid, an activity that is highly practiced at an industrial level (Figure 4.B).
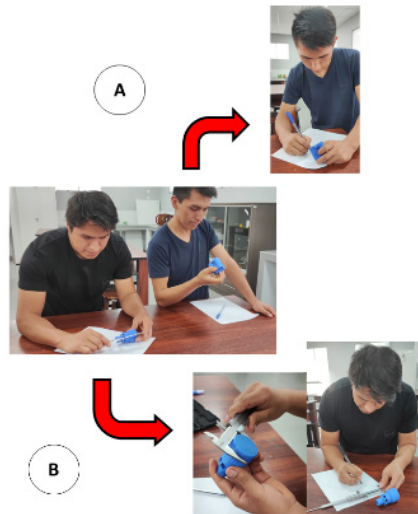

Figure 4: Interaction between the student and the printed solid for the accompaniment in the generation of main views.

This activity, the accompaniment with a 3D printed object, could be carried out as many times as necessary by the student so that they can improve the level of abstraction until the objective planned for the session is achieved. Likewise, this activity can be repeated without the need for teacher support since the student, having the solid, could self-evaluate his work, thus being an activity that could be done remotely as long as the student can have access to the solids manufactured by the 3D printer (Stavridi, 2017). At the end of the session, some isometric views are presented as an activity and the student is evaluated again on the improvement of his level of abstraction.

In summary, according to Figure 5, for the execution of the learning session you can count on the following stages:

1) Presentation of the problem through the generation of views from a geometric solid.
2) a. Preparation of sheet views with possible abstraction problems.
   b. Building-up the views using a CAD platform with possible abstraction problems.
3) Preparation of the solid in CAD software and print settings.
4) Printing of the 3D element.
5) Interaction between students and 3D physical object (positioning of the element in three axes and taking measurements with vernier).

6) Corroborate the successes and clarify doubts about the exercise in progress.

At the end of the session, some isometric views are presented as an activity and the student is evaluated again on the improvement of his level of abstraction.
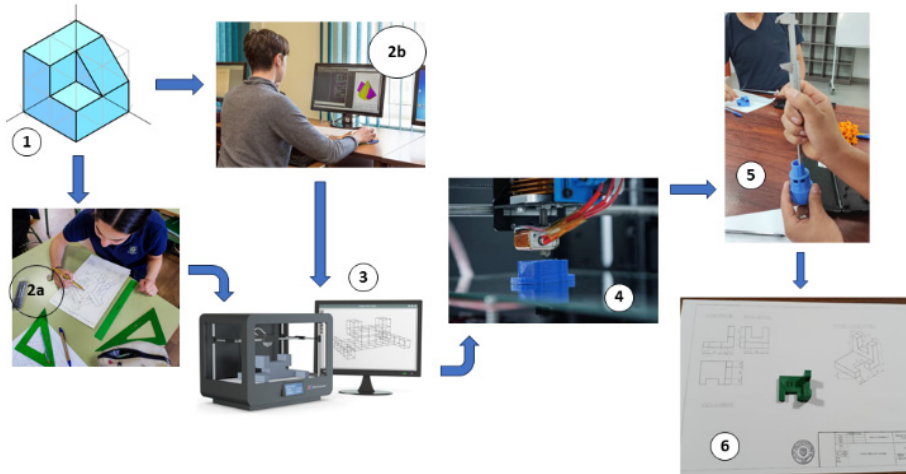

Figure 5: Learning Session Procedure.

3.3   Satisfaction Survey

After applying the session, a satisfaction questionnaire was provided to the students to see the strengths of the session and points for improvement (Funes-Lora et al., 2022).

The questionnaire was adapted from satisfaction surveys related to class sessions according to certain authors (Gallagher et al., 2021), based mainly on seeking the opinion of students about the organization, learning activities, evaluations, motivation, didactic tools, and management and accessibility to 3D printing.

The results of the questionnaire are shown in Table 2, there were 11 students who answered with an "indifferent" option for the question "Assessment exams have allowed you to assess your improvement" and 10 students who considered the handling and printing of 3D not very accessible.

About the evaluations, it is understandable that they found some difficulties when determining the views since the form was intended to be carried out in a shorter time, on the other hand, being an innovative strategy, it is possible that the students thought that the form of evaluation was move away from the traditional.

Table 2: The survey related to didactic session.

Question Description	Disagree	Indifferent	Agree	Totally Agree
- The organization of the session is adequate	-	-	40%	60%
- The learning activities were appropriate for their learning	-	-	40%	60%
- Assessment exams have allowed you to assess your improvement	-	31%	37%	31%
- 3D printed material motivates your imagination to come up with innovation	-	-	20%	80%
- Using the 3D printer, do you think it serves as a didactic tool for the teacher of the subject?	-	-	51%	49%
- Consider that the management of 3D printing is easily accessible	-	29%	43%	29%

On the other hand, although the acquisition costs of 3D printing have reduced considerably, it is still a manufacturing machine that due to installation and use could cause some limitations when acquiring (Petre et al., 2023). In this sense, the options for using the printer would be limited only when the University laboratories can be accessed.

Finally, in the other questions, high acceptance rates were shown, reaching 49%, 60% and 80% with a totally agree criterion.

3.4   Post-Test Results

The results of the Post-test are shown in Table 3, both the control and experimental groups obtained better results (average) than the Post-test, indicating that both methodologies work and improve the level of abstraction for the generation of orthogonal projections of the students.

Table 3: Descriptive statistical measures of the results of the objective test (Post-test)

Group	n	Mean	Standard Deviation	Deviation Average error
Control	37	7.14	2.25	0.37
Experimental	35	8.94	2.461	0.416

Figure 6 shows the frequency distribution of the scores in the pretest and post-test for both groups, in the pretest the most frequent scores were related between 4, 5 and 6 to ten, for the post-test in the experimental group the scores of 8, 9 and 10 to 10 more frequently and in the control group 6, 7 and 8 to 10. The average score of the control group was 7.14/10, improving 20.3% and for the control group it was 8.94/10, improving 38% (Table 3).
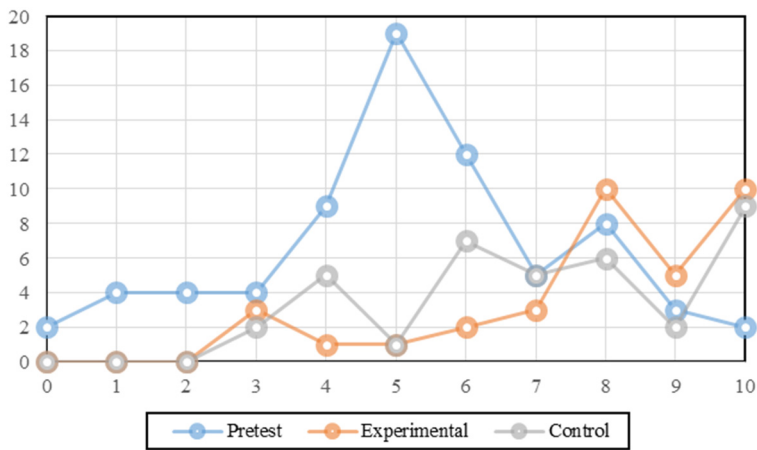

Figure 6: Grades Frequency Distribution

Table 4 shows that in the Levene homogeneity test calculated between the experimental and control groups of the pretest, a significance level of 0.283 was obtained. Therefore, as the significance level obtained was less than the significance level of 0.05, a parametric test will be used to test the hypotheses: t-test for independent samples. From the same table, the values of the t Test for the contrasting of hypotheses, such as $p=0.002 <0.05$, we reject the Ho and accept the Ha, that is, the means of the control group and the experimental group are significant.

Table 4: Levene's test of equality of variances and the t-test for equality of means.

Test	Levene's test of equality of variances		t-test for equality of means					95% confidence interval of the difference	
	F	Sig.	t	gl	Sig. (bilateral)	difference of means	Standard error difference	Lower	Upper
Pre-test	1.169	0.283	-0.073	70	0.942	-0.035	0.476	-0.985	0.916
			-0.073	66.61	0.942	-0.035	0.475	-0.982	0.912
Post-test	0.062	0.804	-3.255	0	0.002	-1.808	0.555	-2.915	-0.7
			-3.255	0.416	0.002	-1.808	0.557	-2.918	-0.697

4. Conclusion

To expose the main contributions of this research to the field of knowledge, it is highlighted that the innovative strategy using 3D printing improves the level of abstraction, allowing students to generate the three main projections (front, top and side) from the isometric view. The investigation showed that the student can lean on the printed element when he presents difficulties in the abstraction process, this means that the teacher has an extra help material during the teaching-learning process of the session and the student could even dispense partially of the orientation of the teacher and could be put into practice even remotely. On the other hand, the student during the session acquired other complementary knowledge and skills that are of great importance for professional training in engineering such as CAD software drawing, also the use and management of the 3D Printer, which is a manufacturing machine and finally the use of vernier that accompanies metrology. To conclude, the proposed methodology turned out to be more significant for the experimental sample taken than the traditional teaching method for improving the level of abstraction of students.

References

Alexis Alvarado Silva, C., Mejia Vasquez, O., & Orlando Gamarra-Rosado, V. (2021). Development of a Virtual Learning Module Using Graphic Interface for Remote Teaching of Photovoltaic Systems. *ACM International Conference Proceeding Series*, 46–52. https://doi.org/10.1145/3450148.3450160

Alhonkoski, M., Salminen, L., Pakarinen, A., & Veermans, M. (2021). 3D technology to support teaching and learning in health care education – A scoping review. *International Journal of Educational Research, 105*. https://doi.org/10.1016/j.ijer.2020.101699

Alvarado-Silva, Carlos A.,Tejeda-Ponce, Alex D., Ulloa-Rubio, Bertha, Salas-Ruiz, Jorge A. & Gaytan-Reyna, Karina L. (2023). Analysis of the Academic Performance of Mechanical-Electrical Engineering Students during the COVID-19 Pandemic: A Case Study in a Private University in Peru. International Journal of Information and Education Technology, 13(5), pp. 867-872. https://doi.org/10.18178/ijiet.2023.13.5.1881

Carlos Vives Garnique, J., Alexis Alvarado Silva, C., Denis Bonilla Bravo, O., & Monteza Perez, H. (2021). Modeling and Simulation of a Magnetic Levitation Virtual Module for Undergraduate Rotodynamic Teaching. *ACM International Conference Proceeding Series*, 19–26. https://doi.org/10.1145/3450148.3450179

De Souza Almeida, M. V., Junior, A. B. A., Junior, E. S. C., Da Silva, E. C. C., & De Mesquita, B. D. N. R. (2020). Educational Robotics as a Teaching Field and Technology Integration: Application of CAD, CAM and 3D printing in structural robot construction. *EDUNINE 2020 - 4th IEEE World Engineering Education Conference: The Challenges of Education in Engineering, Computing and Technology without Exclusions: Innovation in the Era of the Industrial Revolution 4.0, Proceedings*, 1–5. https://doi.org/10.1109/EDUNINE48860.2020.9149541

Funes-Lora, M. A., Fu, A. Q., Webster, N., Burcon, S., & Shih, A. J. (2022). Manufacturing Letters A Common First-Year Undergraduate Engineering Course in Manufacturing based on Industrial Robots and Flipped Classroom. In *Manufacturing Letters* (Vol. 33). www.sciencedirect.com

Gallagher, P., Smith, R., & Sheppard, G. (2021). Use of three-dimensional printing for simulation in ultrasound education: A scoping review. In *BMJ Simulation and Technology Enhanced Learning* (Vol. 7, Issue 5, pp. 410–413). BMJ Publishing Group. https://doi.org/10.1136/bmjstel-2020-000663

Jafri, R., Althbiti, S. M. M., Alattas, N. A. A., Albraiki, A. A. A., & Almuhawwis, S. H. A. (2022). Tac-Trace: A Tangible User Interface-Based Solution for Teaching Shape Concepts to Visually Impaired Children. *IEEE Access*. https://doi.org/10.1109/ACCESS.2022.3228455

Koido, Y., Morikawa, H., Shiraishi, S., Takeuchi, S., Maruyama, W., Nakagori, T., Hirakata, M., Shinkai, H., & Kawai, T. (2013). Applications of 2D to 3D conversion for educational purposes. *Stereoscopic Displays and Applications XXIV*, *8648*, 86481X. https://doi.org/10.1117/12.2008729

Letnikova, G., & Xu, N. (2017). Academic library innovation through 3D printing services. *Library Management*, *38*(4–5), 208–218. https://doi.org/10.1108/LM-12-2016-0094

Lino Alves, J., & Duarte, T. (2022). Teaching ceramic materials in mechanical engineering: An active learning experience. *International Journal of Mechanical Engineering Education*. https://doi.org/10.1177/0306419 0221142096

Mihasan, M. (2021). A beginner's guideline for low-cost 3D printing of macromolecules usable for teaching and demonstration. *Biochemistry and Molecular Biology Education*, *49*(4), 521–528. https://doi.org/10.1002 /bmb.21493

Petre, A. E., Pantea, M., Drafta, S., Imre, M., Țâncu, A. M. C., Liciu, E. M., Didilescu, A. C., & Pițuru, S. M. (2023). Modular Digital and 3D-Printed Dental Models with Applicability in Dental Education. *Medicina (Lithuania)*, *59*(1). https://doi.org/10.3390/medicina59010116

Renner, M., & Griesbeck, A. (2020). Think and Print: 3D Printing of Chemical Experiments. *Journal of Chemical Education*, *97*(10), 3683–3689. https://doi.org/10.1021/acs.jchemed.0c00416

Stavridi, S. (2017). Reforming abstract geometrical ideas through 3D printing: A proposal for experiential e-Making technology in creative education. *ISEC 2017 - Proceedings of the 7th IEEE Integrated STEM Education Conference*, *00*(c), 10–16. https://doi.org/10.1109/ISECon.2017.7910218

Tramonti, M., Dochshanov, A. M., & Zhumabayeva, A. S. (2023). Design Thinking as an Auxiliary Tool for Educational Robotics Classes. *Applied Sciences (Switzerland)*, *13*(2). https://doi.org/10.3390/app13020858

Triantafyllou, A. (2022). Print Your Compass: Using 3D Printed Geological Compasses for Teaching and Research Purposes. *GSA Today*, 32(1), 52–54. https://doi.org/10.1130/GSATG523GW.1

Trust, T., & Maloy, R. W. (2017). Why 3D Print? The 21st-Century Skills Students Develop While Engaging in 3D Printing Projects. *Computers in the Schools*, *34*(4), 253–266. https://doi.org/10.1080/07380569.2017.1384684

Turner, H., Resch, G., Southwick, D., McEwen, R., Dubé, A. K., & Record, I. (2017). Using 3D Printing to Enhance Understanding and Engagement with Young Audiences: Lessons from Workshops in a Museum. *Curator*, *60*(3), 311–333. https://doi.org/10.1111/cura.12224

Üçgül, M., & Altıok, S. (2023). The perceptions of prospective ICT teachers towards the integration of 3D printing into education and their views on the 3D modeling and printing course. In *Education and Information Technologies* (Issue 0123456789). Springer US. https://doi.org/10.1007/s10639-023-11593-z

Villa, V., Motyl, B., Paderno, D., & Baronio, G. (2018). TDEG based framework and tools for innovation in teaching technical drawing: The example of LaMoo project. Computer Applications in Engineering Education, 26(5), 1293–1305. https://doi.org/10.1002/cae.22022

Violante, M. G., Moos, S., & Vezzetti, E. (2020). A methodology for supporting the design of a learning outcomes-based formative assessment: the engineering drawing case study. European Journal of Engineering Education, 45(2), 305–327. https://doi.org/10.1080/03043797.2019.1622653